Development of MATCRO-Soy, a process-based model, for global soy yield estimation

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Introduction

- Soybeans are essential for ensuring global food security, providing a rich source of protein and oil that is mainly utilized in animal feed.
- Challenges may arise due to the rapid growth and environmental changes in soybean cultivation, which include altered soil properties and nitrogen losses (Liu and Herbert, 2008; Smaling *et al.*, 2008).
- GGCMs (Global Gridded Crop Models) assess climate change impacts on crop productivity, but results are inconsistent due to model discrepancies (Jägermeyr *et al.*, 2021). A process-based crop model representing physiological processes can address this issue.
- In line with GGCMs, MATCRO, initially developed for paddy rice fields (Masutomi *et al.*, 2016) provides global crop growth simulations for agricultural studies. MATCRO-Soy was developed in this study to **represent tools for global soybean yield estimation.** It can be further utilized as shown in Figure 1.

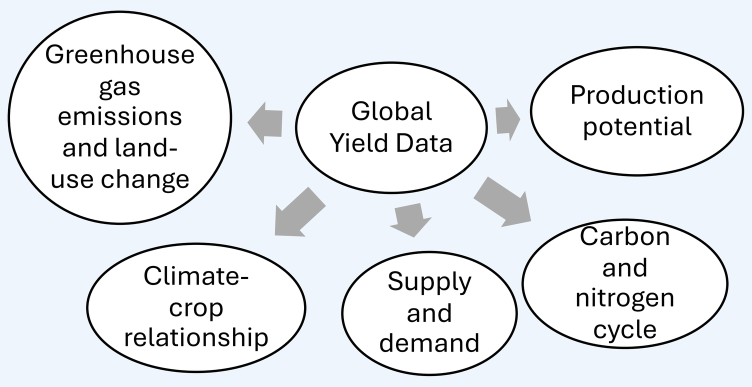


Figure 1. Scheme of simulated yield utilization

Methodology

This study calibrates crop growth model based on an eco-physiological processed-based crop growth model of MATCRO using the present climate data, nitrogen fertilizer input, and soil information. This simulation is *evaluated in global and country-scale data* using FAOSTAT data (FAOSTAT, 2023) and grid cell level using the Global Data of Historical Yield (GDHY) dataset (Iizumi, 2019).

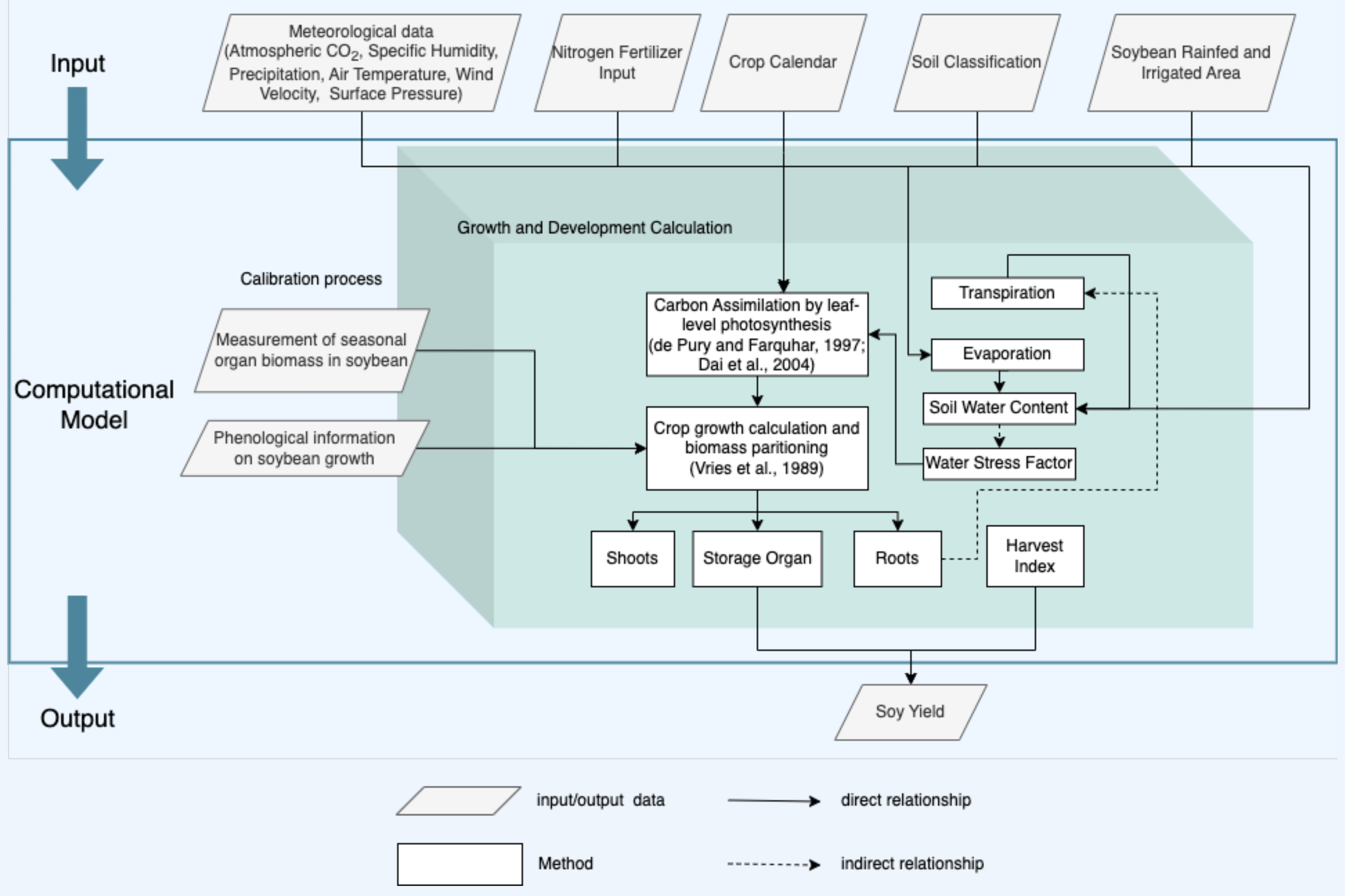


Figure 2. Schematic diagram of MATCRO-Soy

Parameter calibration has included *phenological development*, *seasonal organ biomass, leaf nitrogen, and photosynthesis* based on the available experimental datasets and previous studies. MATCRO-Soy is calibrated to cover a wide range of environmental conditions.

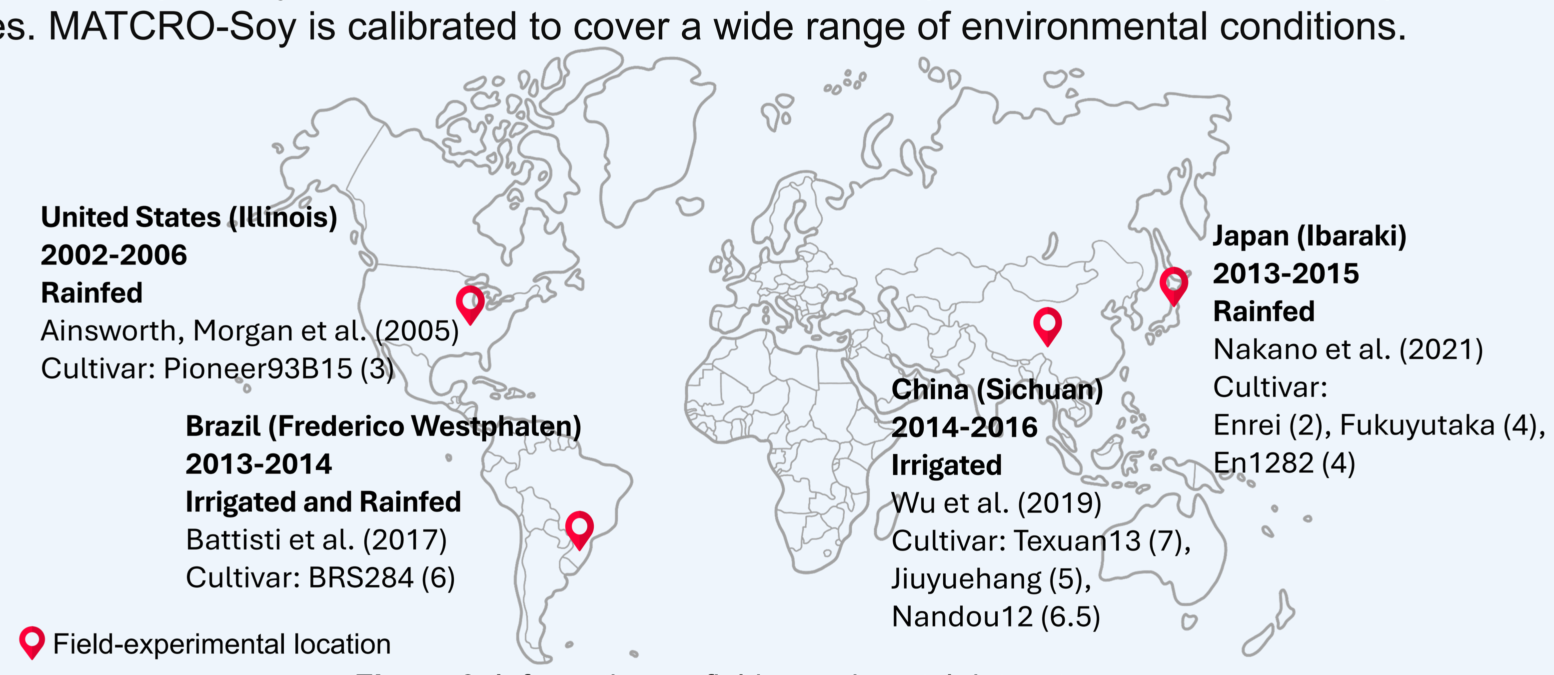


Figure 3. Information on field-experimental datasets

Results

Averaged 35-years yield simulated using MATCRO-Soy ranges between 2000-4000 kg/ha across most regions. Exceptionally high yields are due to favourable environmental conditions, highlighting areas with optimal climate, fertile soil, and advanced agricultural practices. It highlights regions with lower yields due to environmental challenges, resource scarcity, or socio-economic issues. High productivity is noted in the United States, Brazil, and Argentina, which account for 78% of global soybean production (FAOSTAT, 2023) as shown in Figure 4.

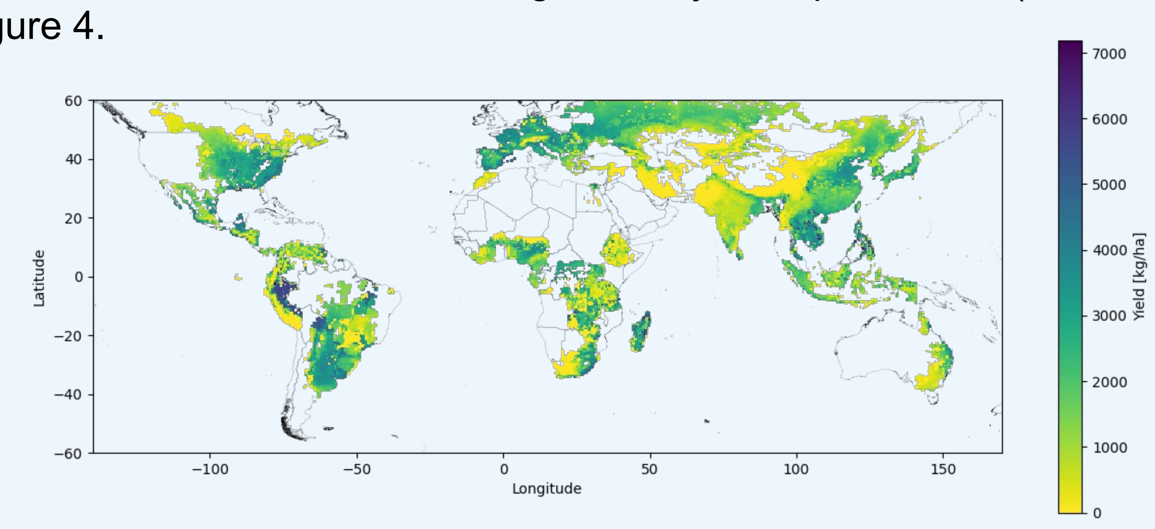
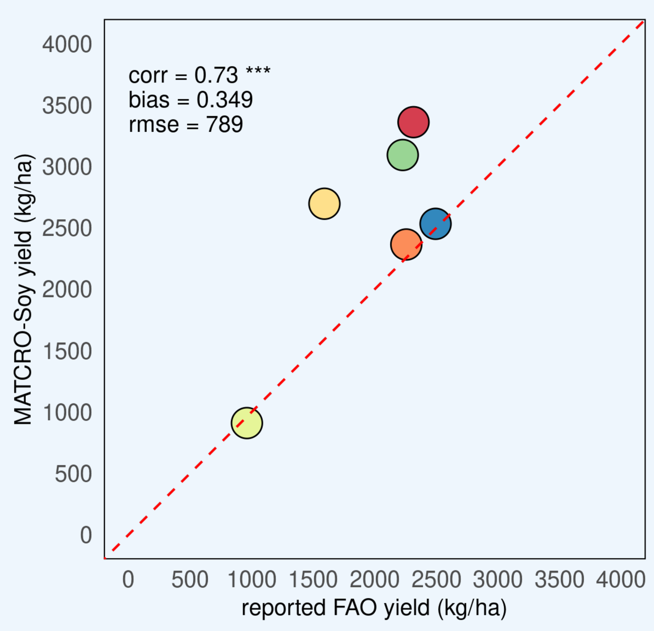


Figure 4. Global map of 35-years averaged soy yield (1981-2014), output of MATCRO-Soy

Figure 5 shows comparison between simulation and reported FAO yield data in 6 major soybean producers' countries, with Pearson correlation value 0.73 (p-value < 0.01) and relative bias of 34.9%. This model could capture the environmental variability for soybean growth. Despite annual differences as shown in Figure 6, yields from 1981-2016 align well with top producers with a correlation over 0.50 (p < 0.001) except for China and India.



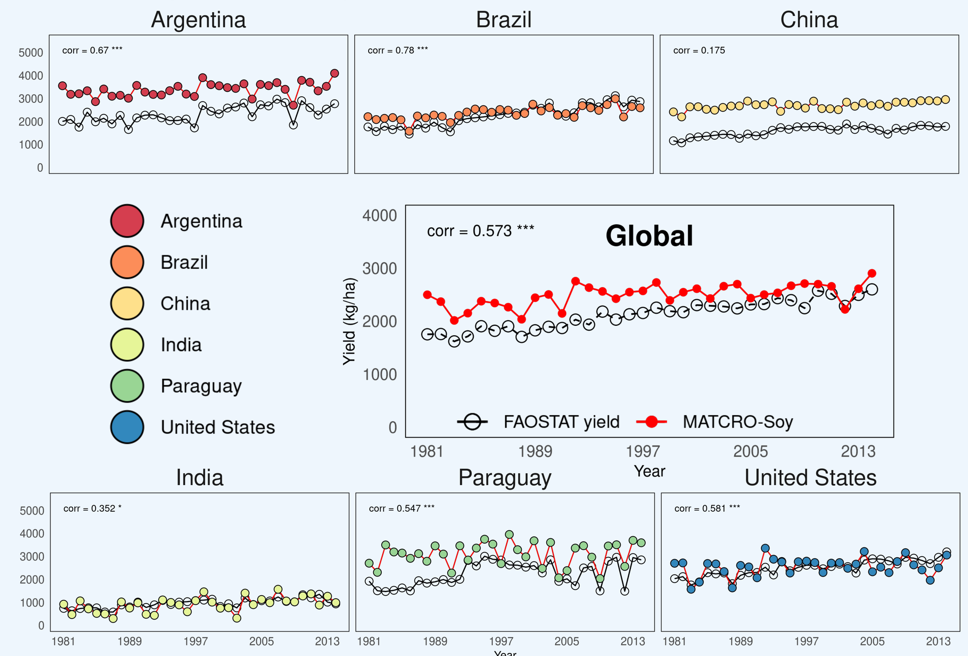


Figure 5. 35-years averaged country yield (1981-2014) comparison in 6 major soybean producing countries. *** means significance (p-value < 0.001)

Figure 6. Interannual variability between simulated yield by MATCRO-Soy and FAOSTAT data in global scale and country scale (6 major soybean producer countries)

High correlation areas, shown in dark blue, are found in the United States, Argentina, South Africa, and India, with grid cell correlations mostly ranging from 0 to 0.5 (Figure 7). This suggests some regions have high accuracy, while others need further investigation.

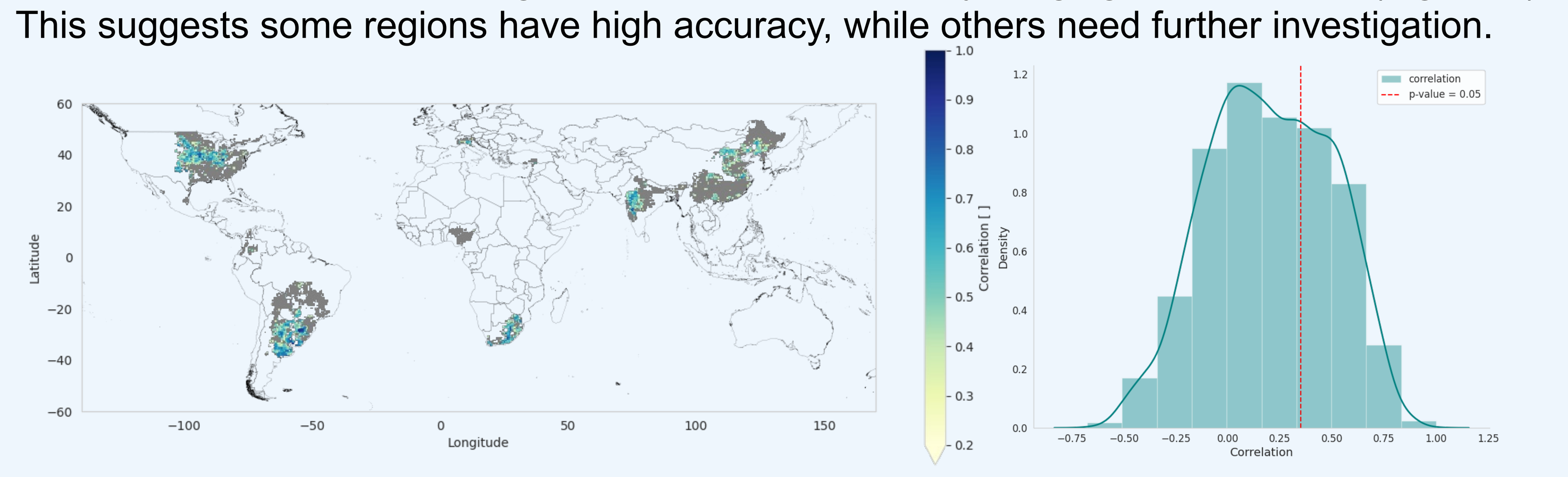


Figure 7. Time series correlation between simulated soy yield with GDHY dataset in global map (left) and density distribution (right) after removing trends from 5-year moving average, grey colour shows comparison which has no significance.

Conclusion

- The study shows promising results in model performance which is comparable with other studies (Müller *et al.*, 2017; Minoli *et al.*, 2022; Ma *et al.* 2022). MATCRO explains global soy yield under various conditions, showing a strong correlation (73%) with historical FAO yield data for top producers.
- MATCRO-Soy is a valuable tool for studying greenhouse gas effects on crop responses and future soybean production, providing critical insights for decision-makers and stakeholders aiming to improve agricultural sustainability and food security.

Reference/Footnotes

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